Everything is a tradeoff

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FMRI Course
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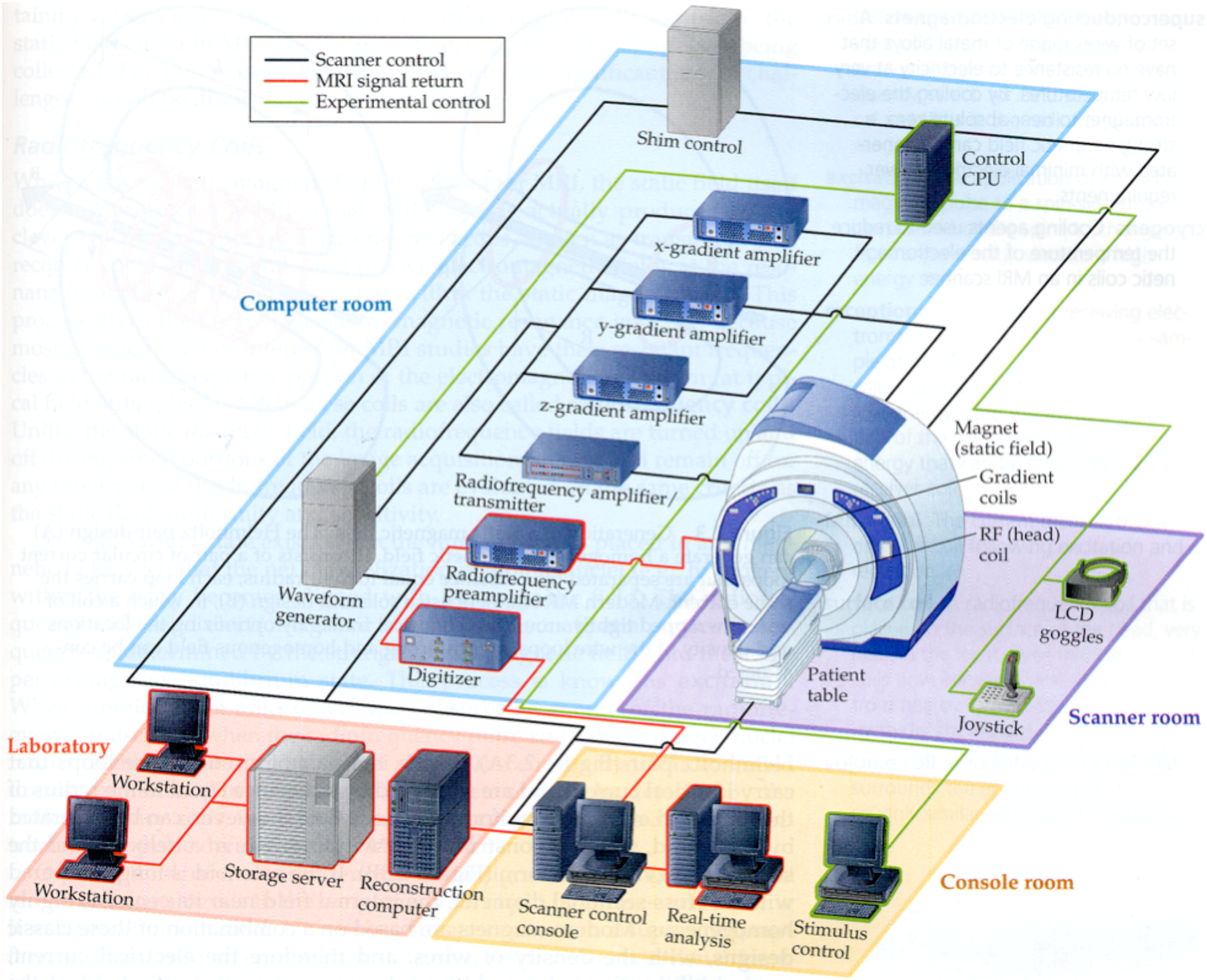
Interrupt early and often.

Nothing is free

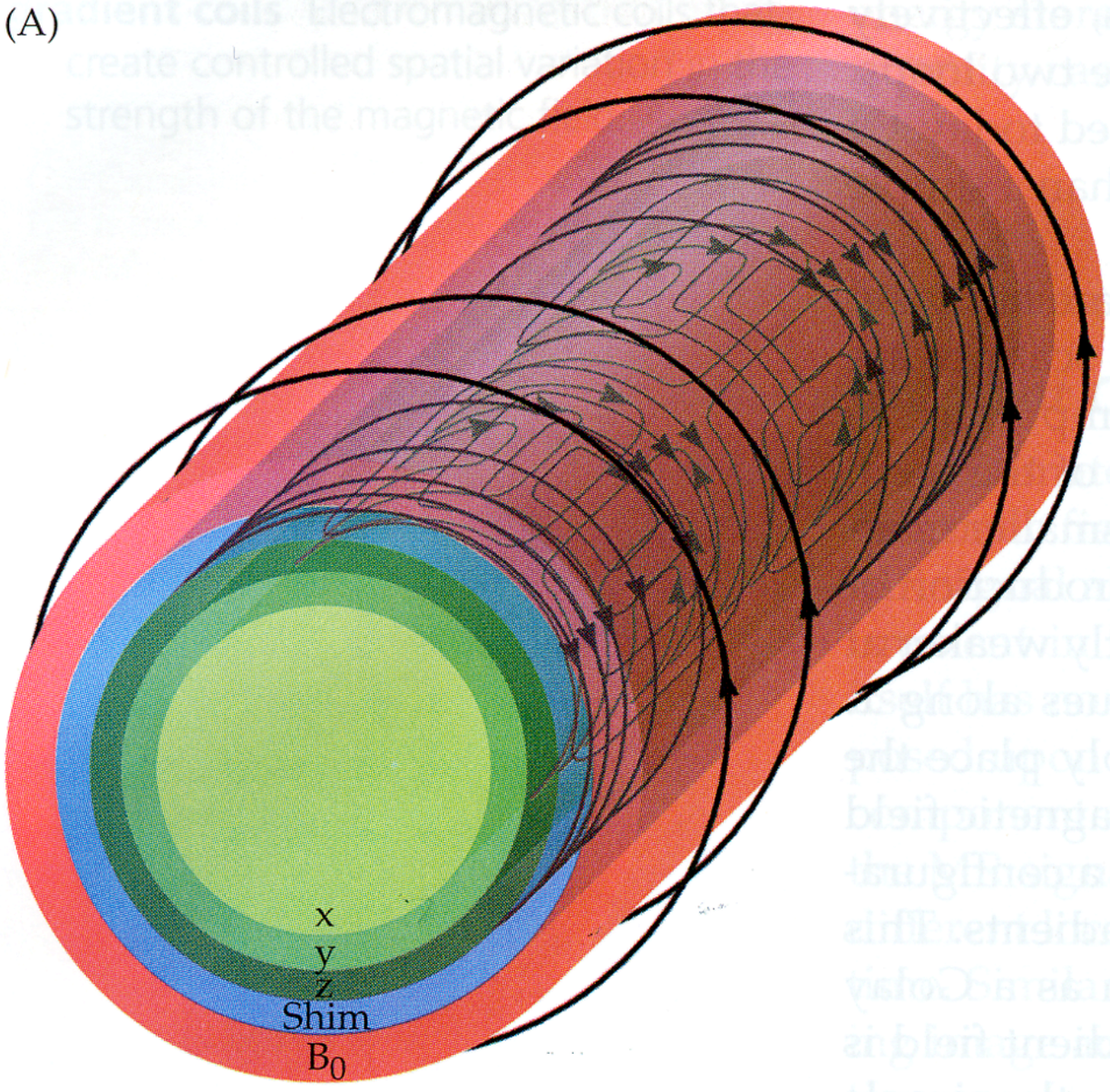
fast, good, cheap
... chose two

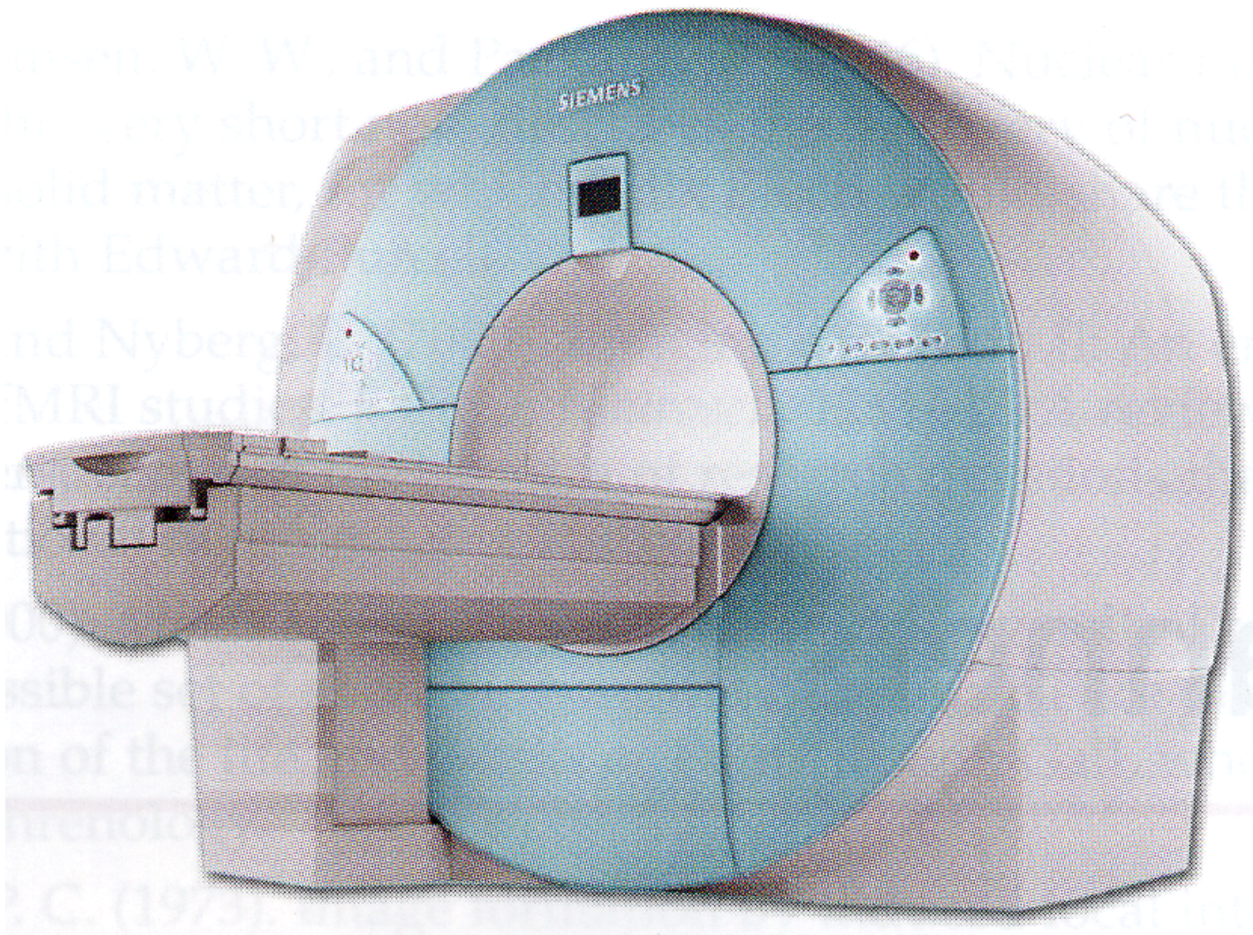
The Hardware



Magnet and Gradients

(A)



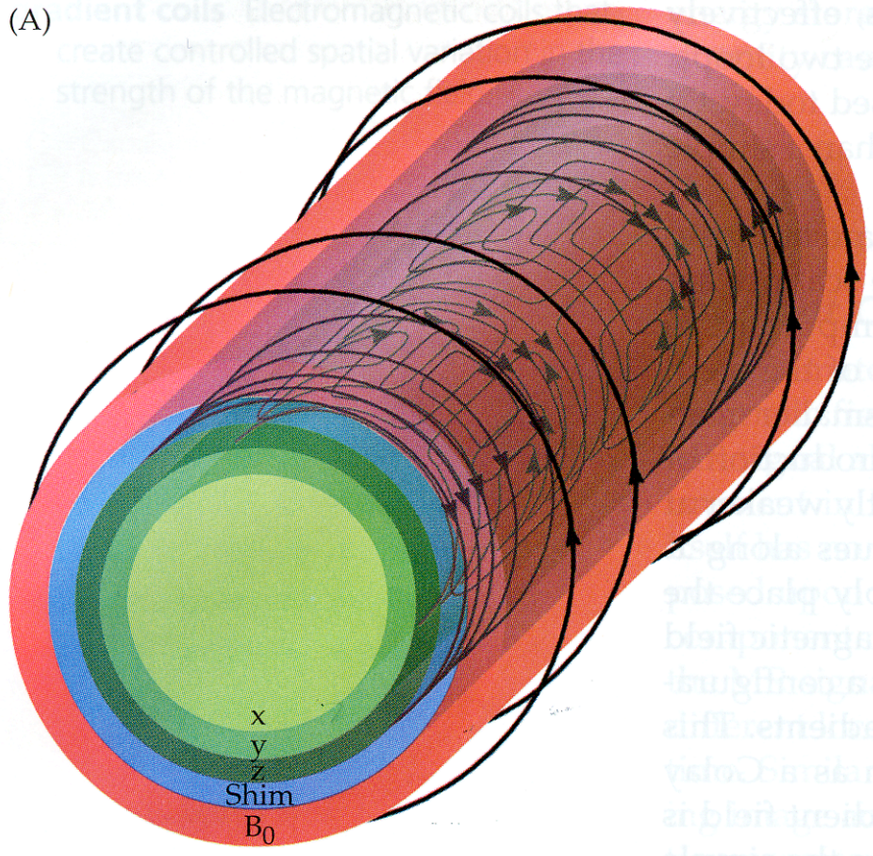


Magnet

- field strength
- bore size
- length/weight
- self-shielded
- homogeneity/shims
- helium boiloff

$1,000,000/Tesla

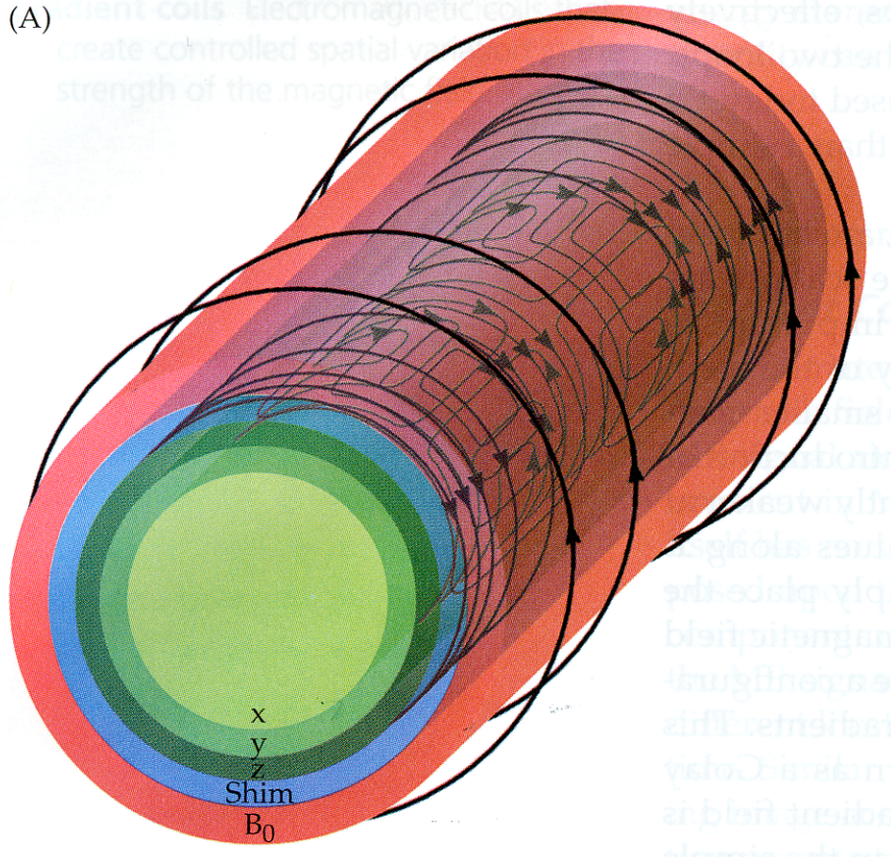
(A)



Gradients

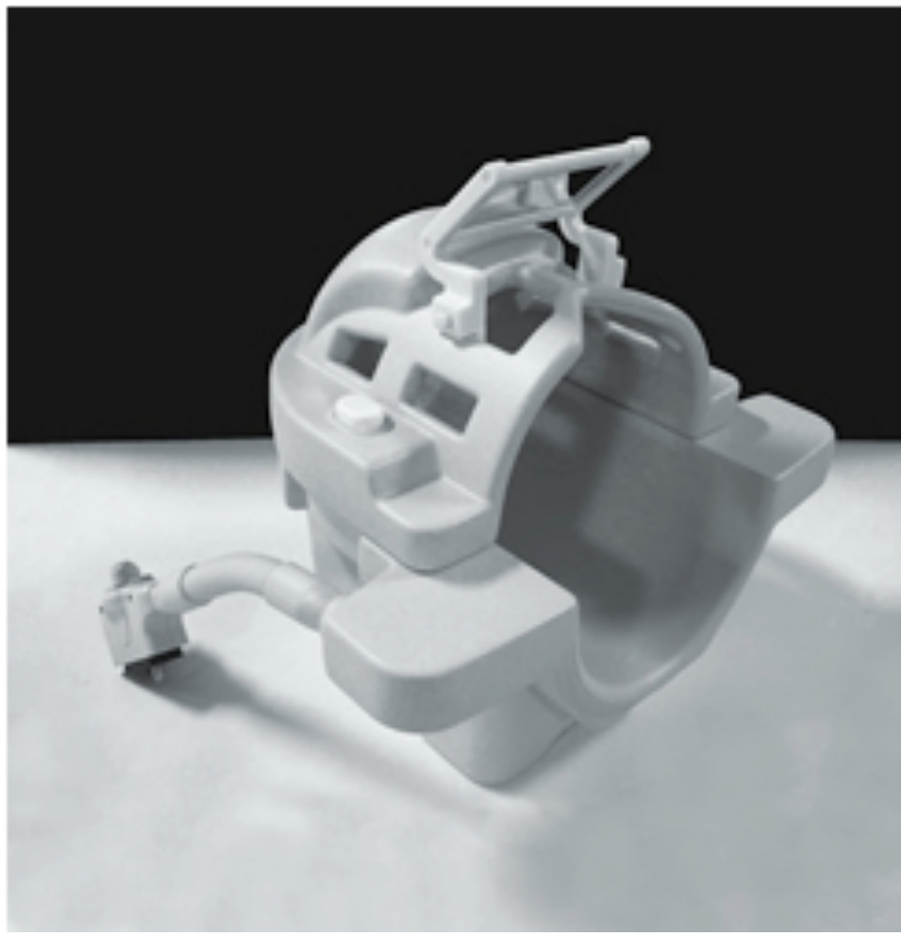
- size (head/body)
- strength
- slew rate
- duty cycle
- linearity
- eddy currents
- water cooling
- vibration/acoustics

(A)



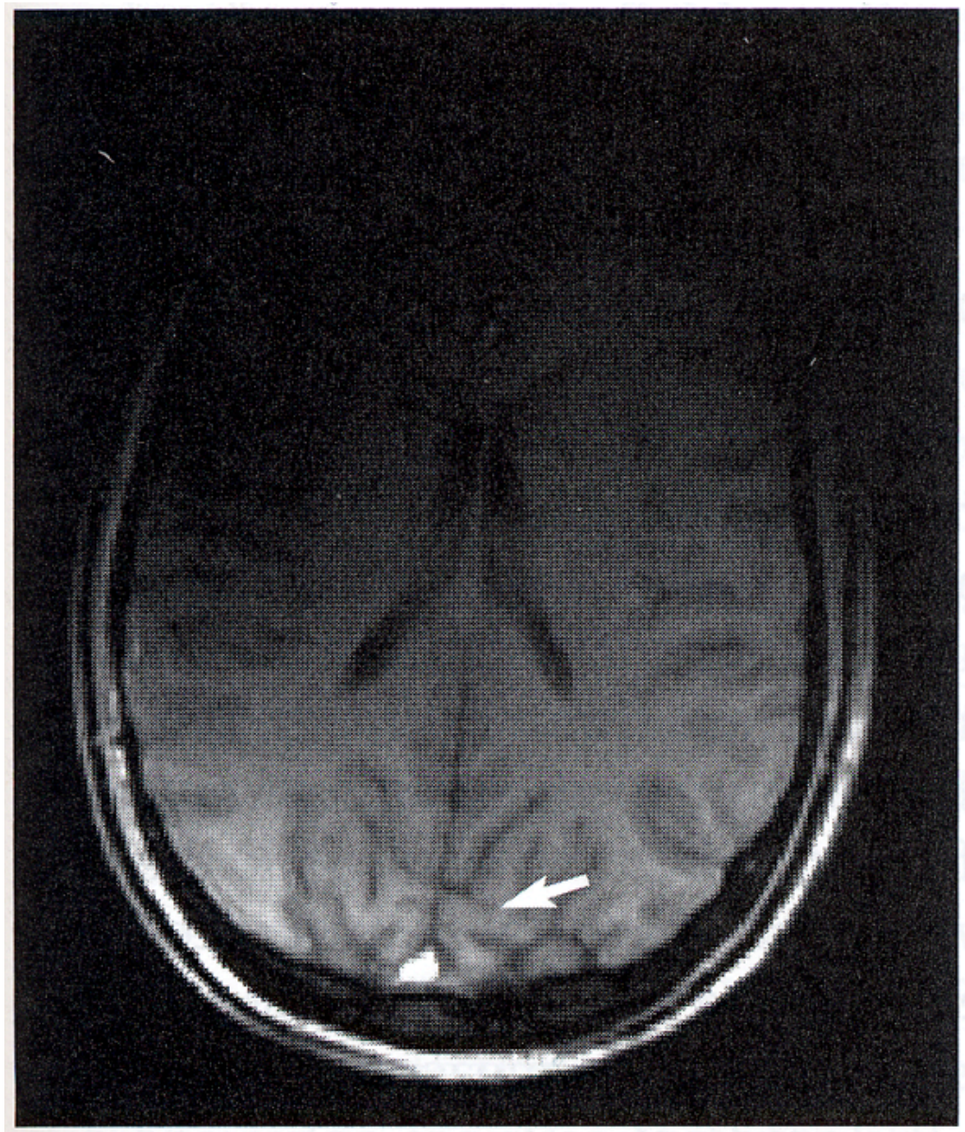
RF Coils

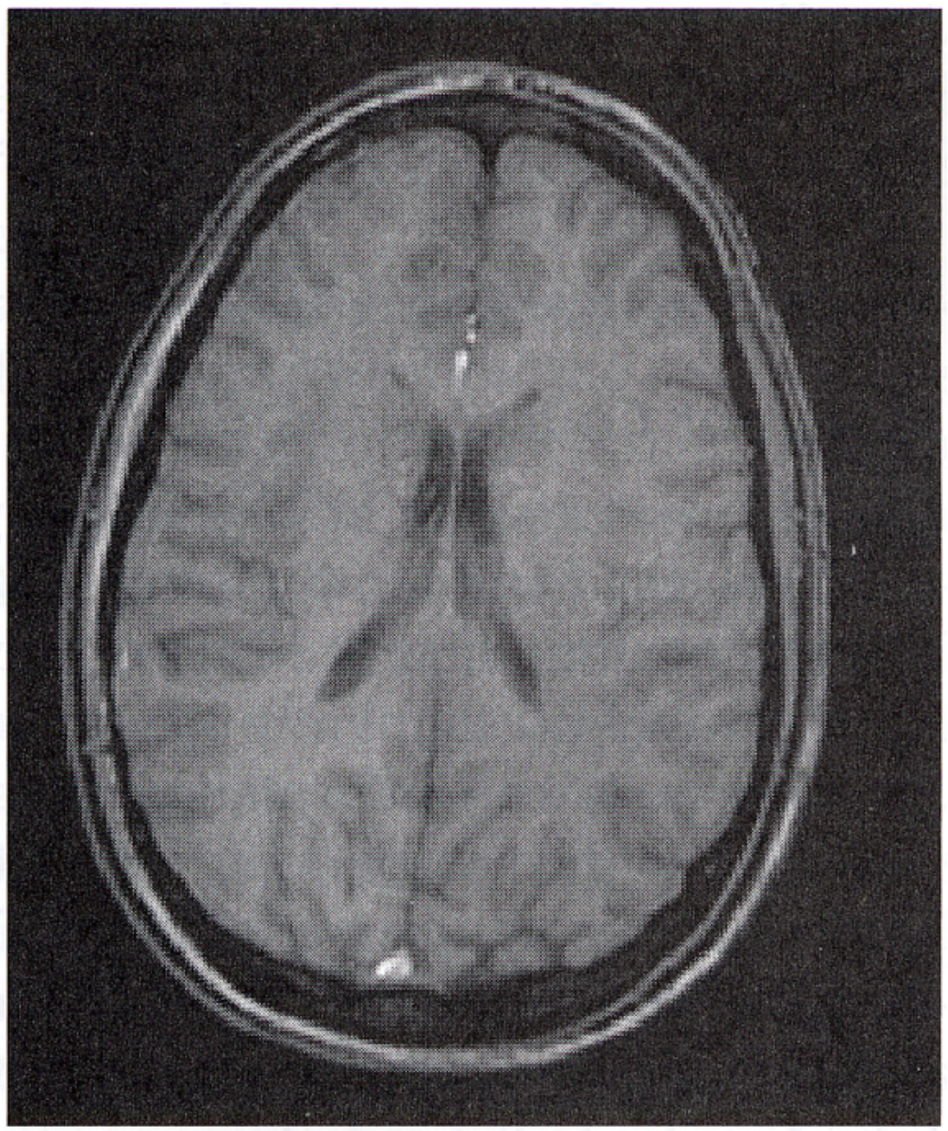
- Receive coil
  - size/shape/coverage
  - element # and arrangement
  - mechanical design/robustness
- Transmit coil
  - head/body Tx
  - multi-channel Tx
- FDA Approval, warrantee and service



3T 32 channel head
Rx array $80k

Surface Coils vs Volume Coils





Tradeoff uniformity for increased SNR locally

Amplifiers

- Lots of Amps
  - Shims
  - Gradients
  - RF Transmit
  - RF Receive
- Issues
  - gain
  - noise figure
  - stability
  - duty cycle

Tradeoffs - each optimized differently

Digitizers, computers

- Digital to Analog
  - Gradients, RF waveforms
- Analog to Digital
  - RF Receiver
  - Physiology monitors
  - Sensors (Temp, Flow)
- Computers
  - sequencer, embedded monitors, recon engine
- Optimization Criteria
  - Dynamic range
  - Fidelity (Accuracy)
  - Speed
  - Hardware architecture
    - CPU speed, RAM
  - Software architecture
    - real-time, parallel

Ancillary equipment

- Projectors
  - resolution, color, speed
  - lens system optics throw, image size
- Interface devices
  - mechanical design/robustness
  - ease of use with stimulus programs
- Physiological monitoring
- Eye-tracking, EMG, EEG, ...
- FDA Approval, warrantee and service

~~fast, good, cheap~~

~~... chose two~~

SPEED KILLS

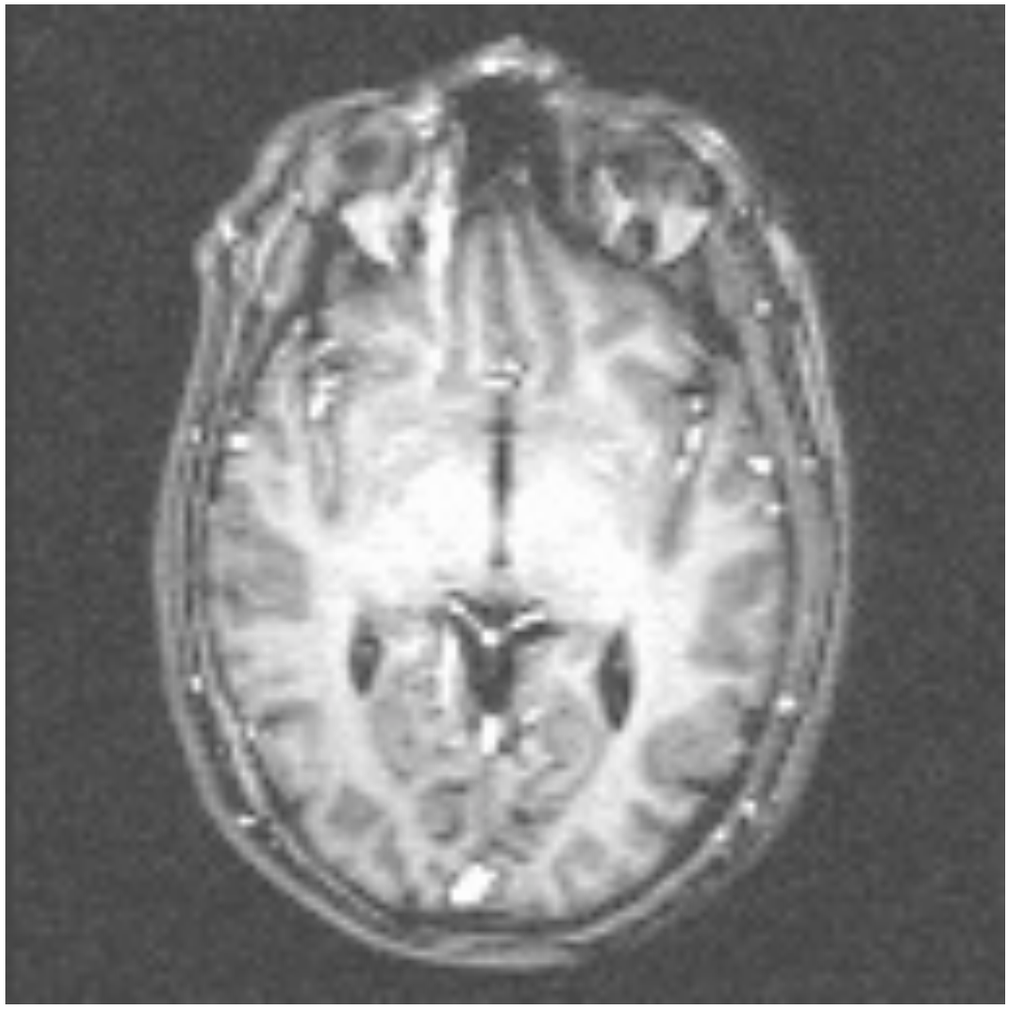
speed vs image artifacts

speed vs coverage

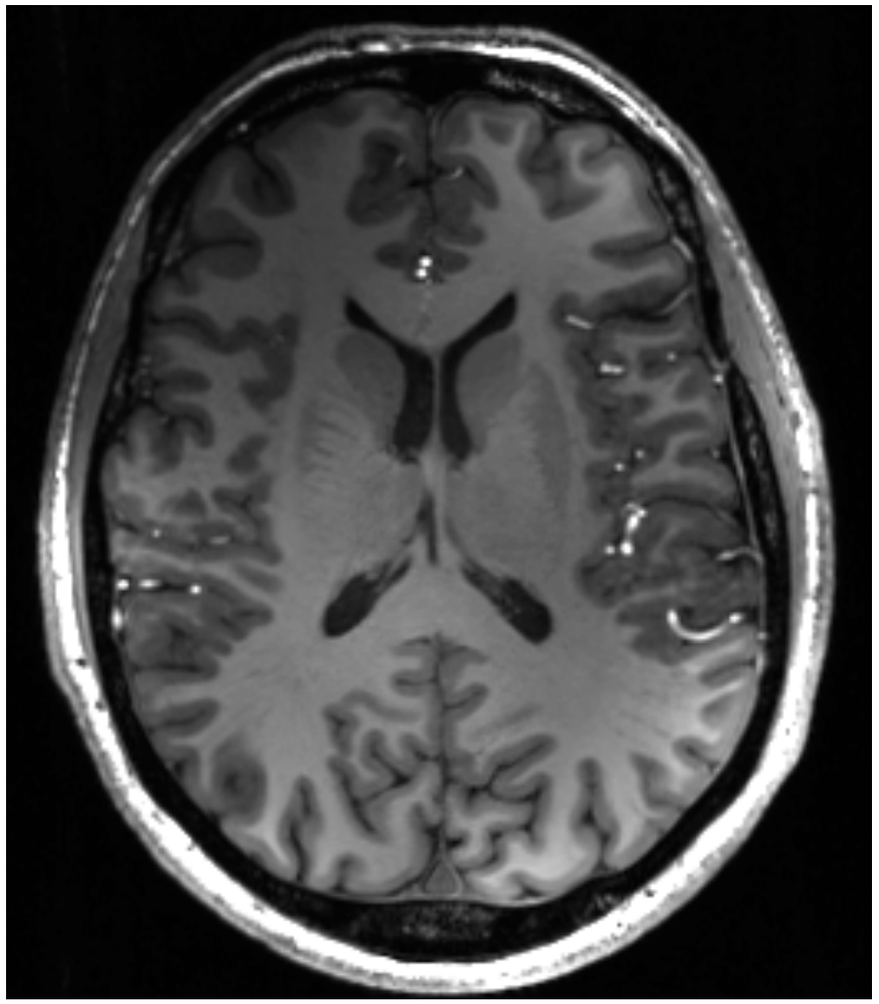
speed vs resolution

speed vs signal to noise ratio

Hardware Matters



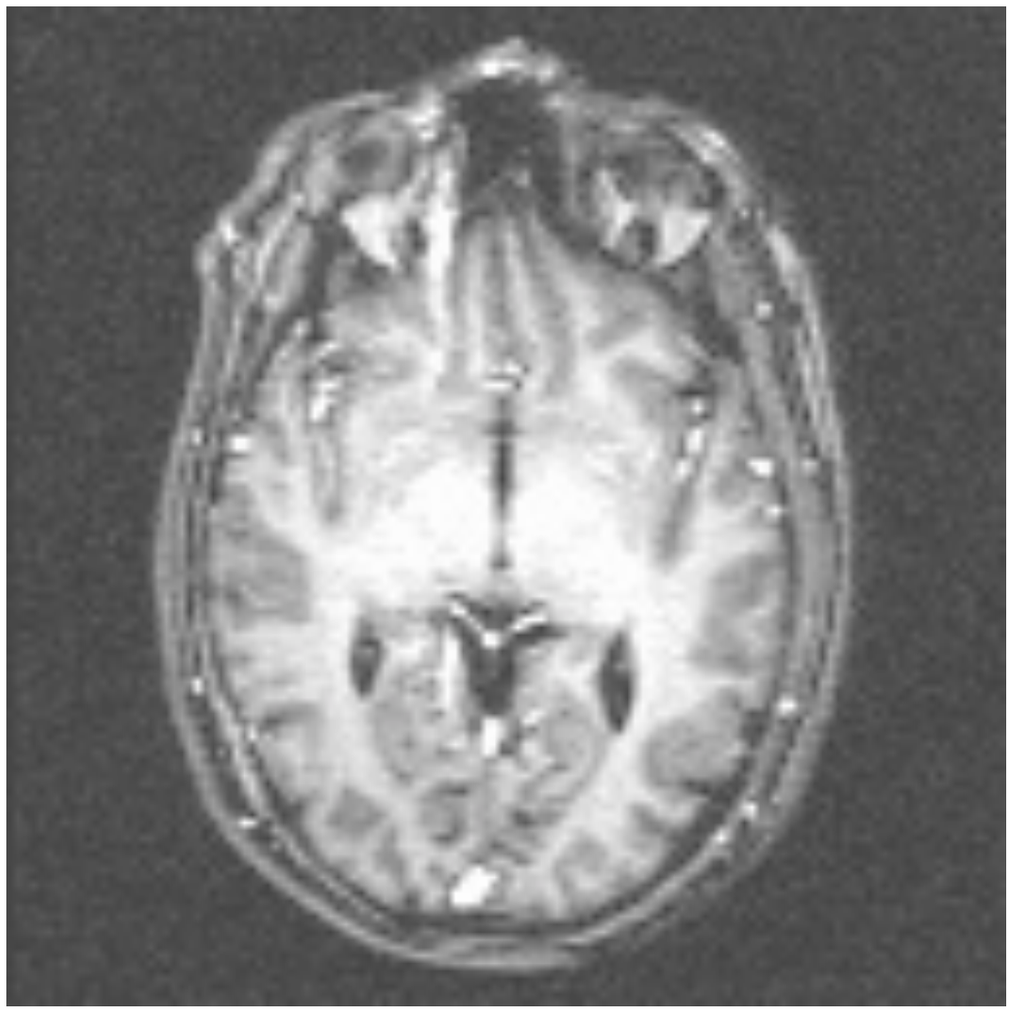
1 mm, 10 min
3T, Volume Coil



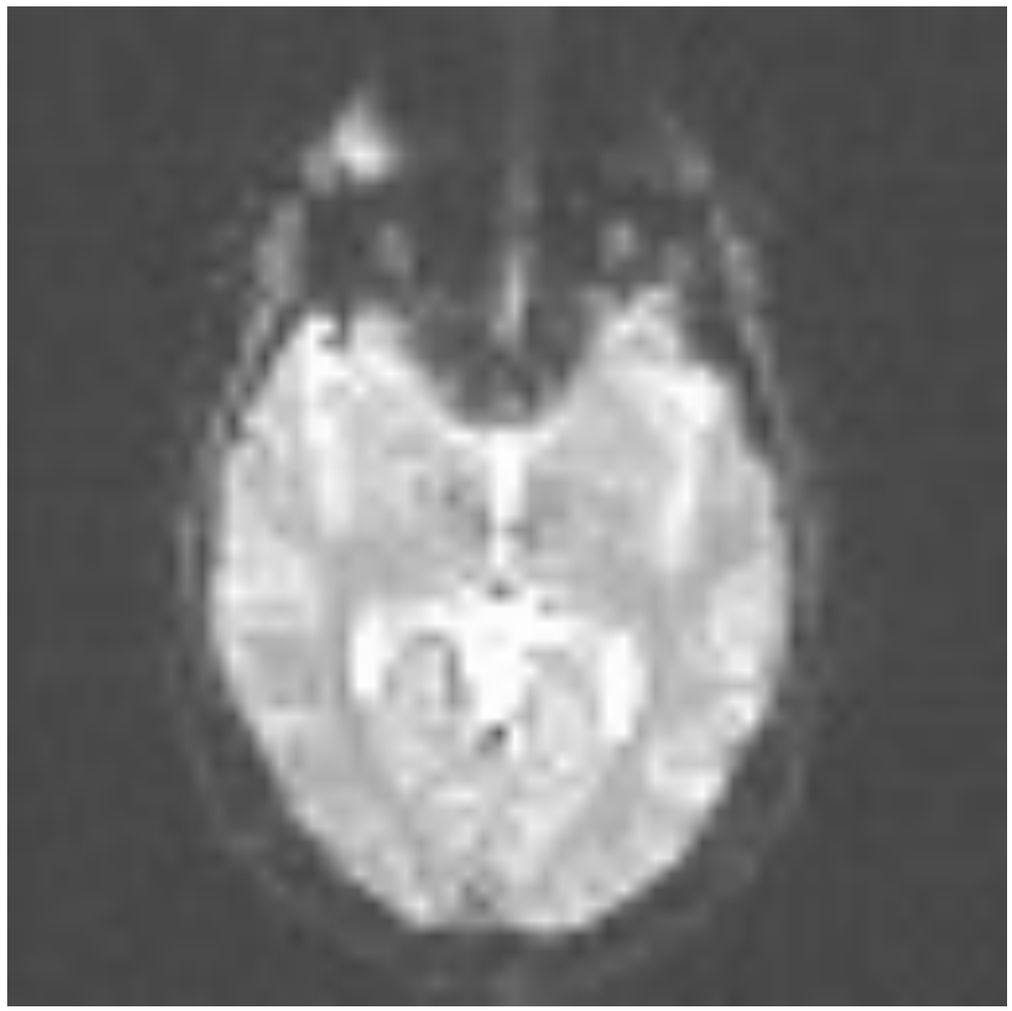
0.7 mm, 10 min
7T, Rcv Array

Attainable SNR, CNR, resolution, speed depend on hardware

Speed vs Image Artifacts



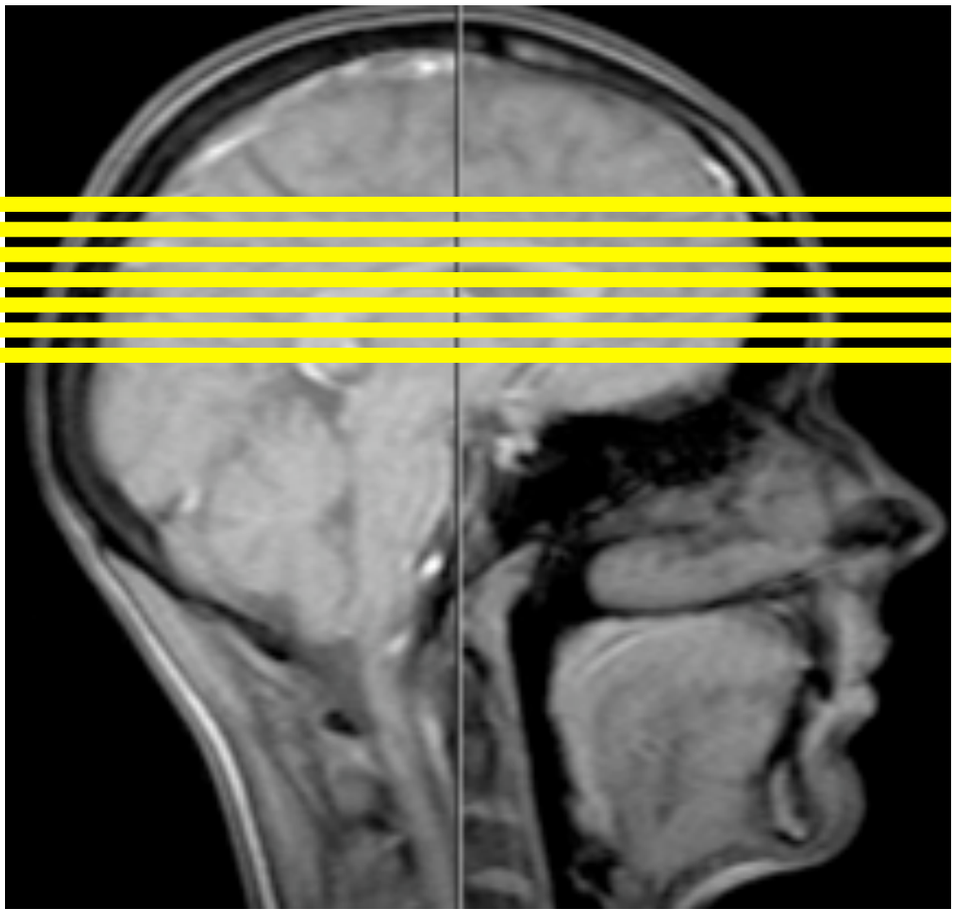
1 mm, 10 min

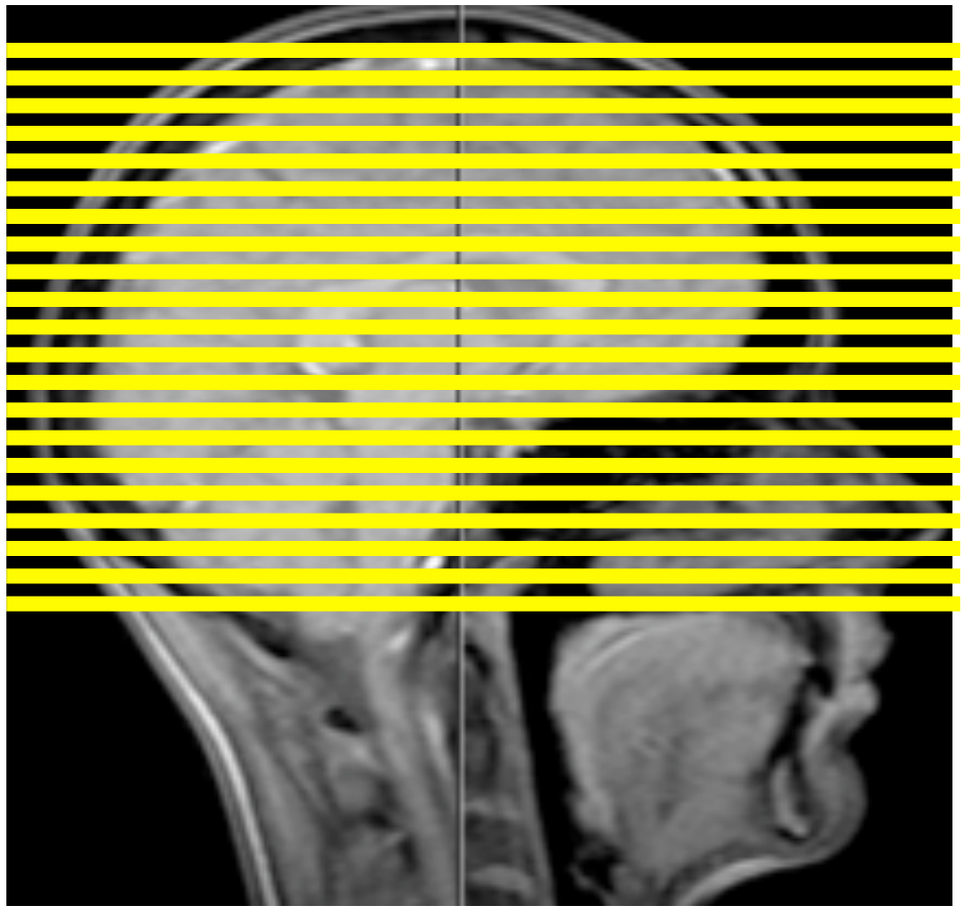


3 mm, 2 s

See Vinai's lecture next week.

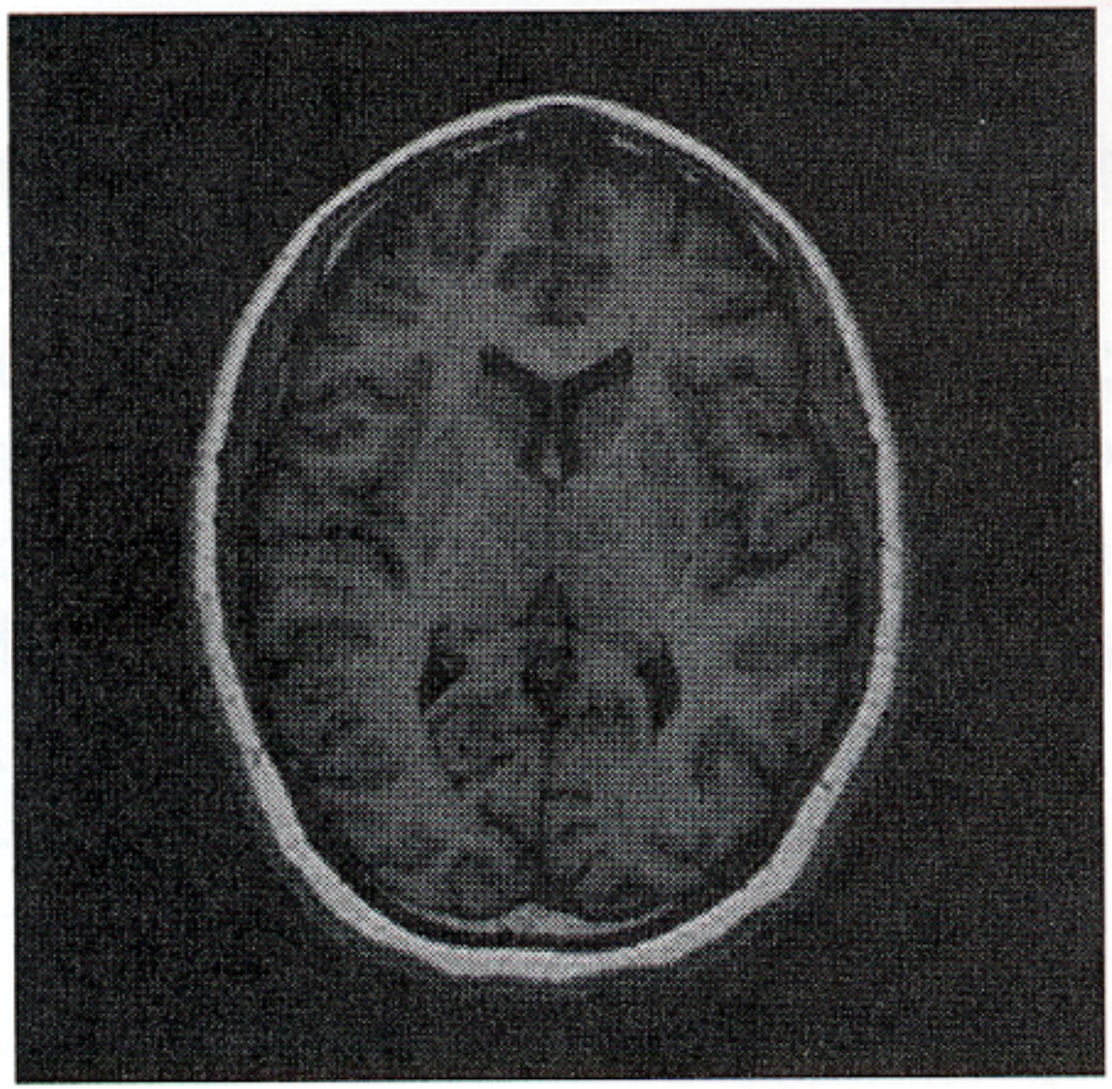
Speed vs Coverage



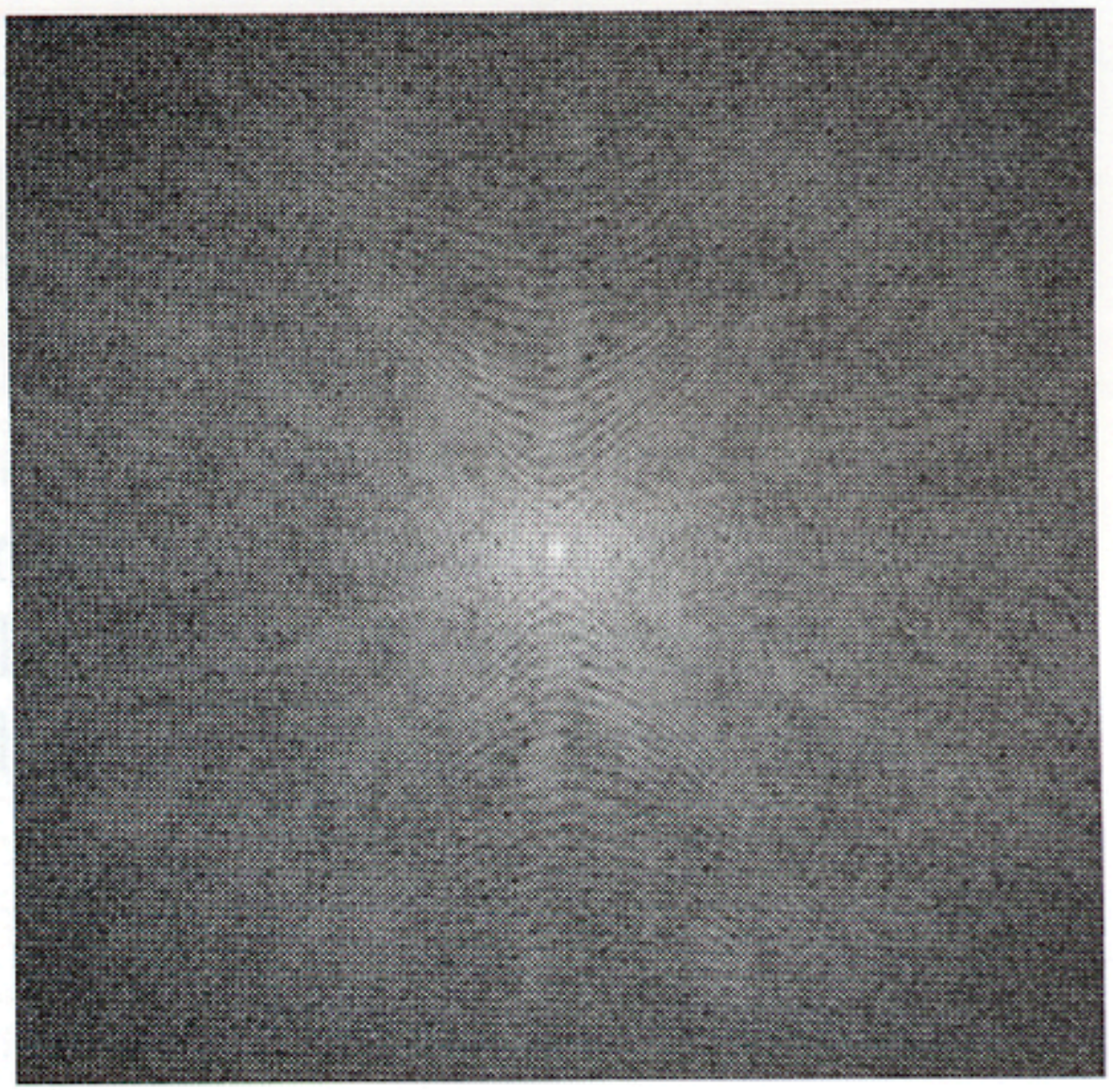


Increasing number of slices costs time

Speed vs Resolution

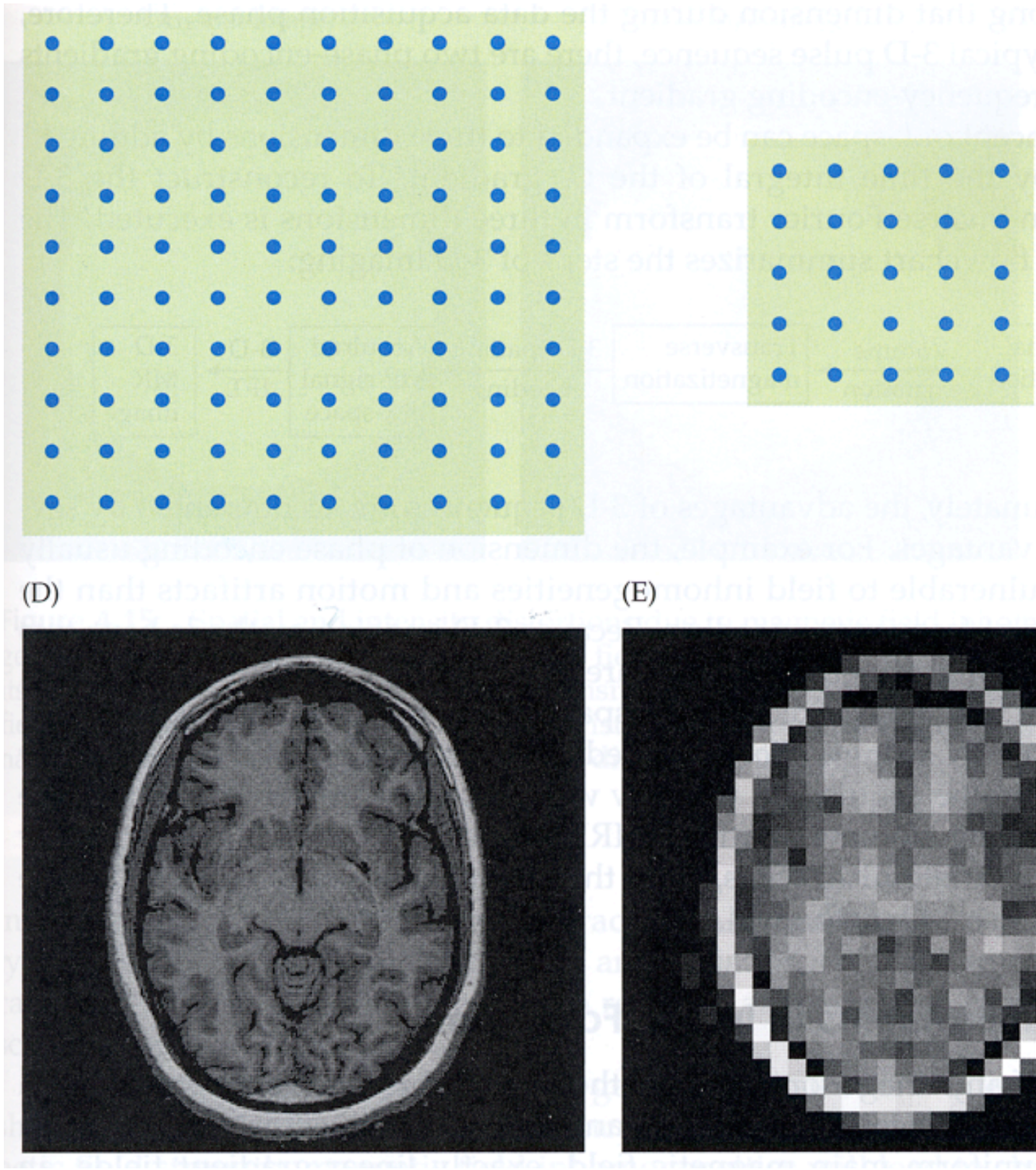


Image



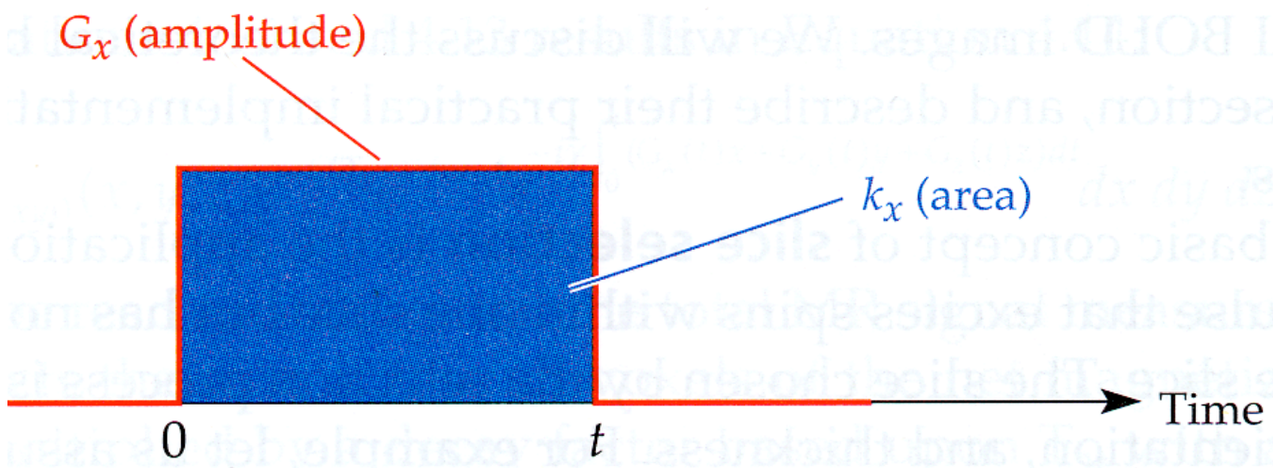
k-space

Speed vs Resolution



Speed vs Resolution

Increasing number of pixels costs time



The k number:

$$k_x \equiv \gamma \int_0^t G_x(\tau) d\tau$$

Signals and Noises

- Signal amplitude depends on many things
  - Acquisition parameters
  - Tissue properties (T1, T2)
  - Hardware, e.g. field strength, coil sensitivity

- Noise amplitude depends on many things
  - electrical: coils, receivers, amps
  - mechanical: vibration
  - physiological: respiration, subject motion, cognitive

Simple model of noise

Additive

d(j) = s(j) + n(j)

Independent

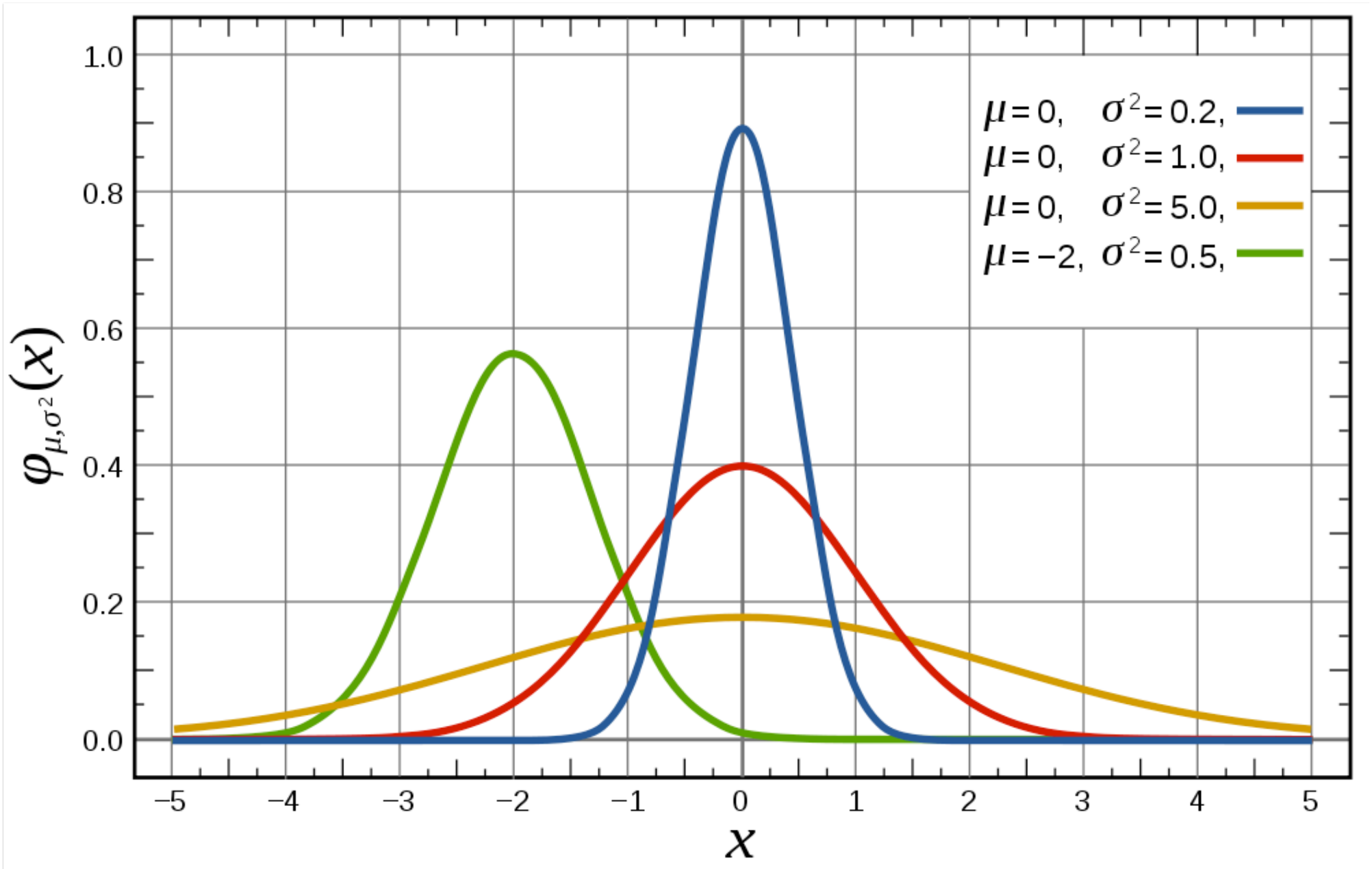
noise at j is independent of noise at other times

Normally distributed

drawn from a normal distribution with 0 mean

Simple model of noise

Normal distribution (Gaussian)



Simple model of noise

- If noise is sum of many Gaussian noise sources then total noise is also Gaussian - variances add
- If the number of measurements becomes large, the noise distribution looks Gaussian
- If noise is not Gaussian, then often a transformed version of the data is

Thinking about additive Gaussian noise gets us almost all the intuition we need

Speed vs Accuracy

- If noise is Gaussian accuracy improves as 1/sqrt(N)
- This applies to almost everything in MR
  - time, resolution, coverage, etc.
- Except for the physiological stuff and the other stuff that is not Gaussian

MATLAB Demo